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CONTENTS

Review of the Nitrogenous Constituents of the Potato—*C. F. Woodward and E. A. Talley* 205

Observations on the Effectiveness of DDT, Parathion, and Malathon against the Iris Whitefly on Potatoes—*B. J. Landis and K. E. Gibson* 213

The Box as a Container for Potatoes—*R. B. Hopkins* 221

POTATO NEWS AND REVIEWS

The Golden Nematode in Britain—*B. G. Peters* 226

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REVIEW OF THE NITROGENOUS CONSTITUENTS OF THE POTATO[1]

NUTRITIVE VALUE OF THE ESSENTIAL AMINO ACIDS

C. F. Woodward and E. A. Talley[2]

The potato has been a primary dietary constituent of modern civilizations. There may be some question about the relative role of the potato in the diet of certain medieval populations, such as the early South American Indians, but the importance of this foodstuff for centuries to inhabitants of Europe and the British Isles is a matter of record. Today the potato is still the most important vegetable for a large portion of the world's population. In spite of this historical background, the complete nutritional value of the potato has not been fully appreciated. The fact that starch constitutes two-thirds to three-fourths of its dry weight has directed our attention away from its important vitamins, minerals, and amino acids. Within the past two decades, it has been recognized that the potato is an important supplier of vitamin C. It was reported 25 years ago, however, that human adults were kept in nitrogen balance and in good health for as long as 5 months when fed diets consisting solely of potatoes and a small amount of fat (9, 12). This indicates that, with the possible exception of fat and fat-soluble indispensable nutrients, potatoes contain practically all essential dietary factors.

It is the purpose of this paper to review the nitrogenous constituents of potatoes with particular emphasis on the nutritional value of the eight amino acids indispensable to man.

Table 1 shows the range of nitrogen contents of several varieties of potatoes, reported by Neuberger and Sanger in 1942 (10).

Total N ranged from 0.24 to 0.36 per cent of fresh weight. Our comparable analyses ranged from 0.20 to 0.42 per cent. On a moisture-free basis, the N values are 1.16-1.95 per cent. The percentage of N compounds can be estimated on a dry-weight basis by multiplying the 1.16 and 1.95 extremes by 6.25. In this case, the N-containing compounds comprise 7.2 to 12.2 per cent of the dry matter—or, let us say, 10 per cent for a general average. There is a rather wide variation in all these percentage N values.

Trace Compounds

In addition to the amino acids, amides, and proteins, numerous constituents, present in only trace quantities, should be included in any consideration of the nitrogenous materials. These trace compounds, mentioned by Burton (1), include the enzymes, vitamins, the alkaloid solanine, and other basic nitrogen compounds.

[1]Accepted for publication May 29, 1953.

[2]Eastern Regional Research Laboratory, Philadelphia 18, Pa. One of the laboratories of the Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture, Washington, D. C.

TABLE 1.—*Nitrogen contents of several varieties of potatoes.*

Total N, as per cent of fresh weight	0.24— 0.36
" N, " " " " dry "	1.16— 1.95
Protein N, as per cent of total N	37.0 —63.7
Asparagine N, " " " " " N	11.8 —27.0
Glutamine N, " " " " " N	7.6 —19.7
Alpha-Amino-acid N, " " " " " N	6.4 —12.8
Basic N, " " " " " N	20.4 —27.7

The following enzyme systems have been reported: Tyrosinase, amylase, catalase, polyphenoloxidase, aldehydrase, phosphatase, phosphorylase, glyoxalase peroxidase, sisto-amylase, dehydrogenase, and zymohexase.

The amylase and/or phosphorylase systems are responsible for the formation of sugars during cold storage. The tyrosinase system catalyzes one form of enzymic discoloration in peeled potatoes. Further understanding of these complex systems could contribute materially to the solution of practical problems encountered in the handling, storing, and processing of potatoes.

The following nitrogen-containing vitamins have been found in the potato: Thiamin, (B_1); riboflavin, (B_2); the anti-pellagra factors, nicotinamide and trigonelline; pyridoxine (B_6); and choline. One would probably assume the presence rather than the absence of other N-containing vitamins, such as pantothenic acid, biotin, folic acid, and p-aminobenzoic acid.

Other trace compounds include adenine, cadaverine, xanthine, hypoxanthine, solanine, and guanine. Of these, the alkaloid solanine has received most attention. This alkaloid is present primarily in or near the skin, and unusually high concentrations have been attributed to exposure of the tubers to sunlight in the field. Chemically, solanine is probably an alkaloidal glycoside, since on hydrolysis it yields glucose, galactose, rhamnose, and the alkaloid solanidine. Several chemical formulas have been proposed.

THE AMIDES

Extensive work on the amide fraction of potatoes has been done by F. C. Steward (15). The principal amides are asparagine and glutamine, and they contain, as shown in table 1, from 11.8-27.0 and 7.6-19.7 per cent of the total nitrogen, respectively. The amide nitrogen of glutamine is more easily hydrolyzable than that of asparagine. When plants receive nutrients rich in ammonia, they produce large quantities of one of these amides.

Vickery, Pucher, and Clark (19) have suggested that in any green plant only one of the amides detoxifies ammonia and that the function of the second amide is by no means clear.

The easily hydrolyzable amides are regarded as reactive intermediates between amino acids and more stable amides on the one hand and proteins on the other. Glutamine and glutamic acid in particular appear to be important in transamination reactions catalyzed by enzyme systems.

Additional nutritional significance is provided by the observation of Rose, Oesterling, and Womack (14) that the growth of weanling rats was definitely stimulated by the addition of glutamic acid to a diet that

was adequate with respect to the 10 essential amino acids. In short, the nutritionally important amides, asparagine and glutamine, are present in relatively large amounts in potato sap.

The Amino Acids

When Dent, Stepka, and Steward (4) in 1947 analyzed a solution containing the soluble, non-protein nitrogen fraction of the potato, by the paper chromatography technique, they hit the proverbial jackpot. They reported "By this means, positive and, we believe, unequivocal identification has been achieved of 21 amino acids as normal constituents of the alcohol-soluble nitrogen of potato tuber tissue and three more still await identification." Positive identification was reported for cystine, aspartic and glutamic acids, serine, glycine, asparagine, threonine, alanine, glutamine, *alpha*-amino-n-butyric acid, histidine, arginine, lysine, methionine sulfoxide, proline, valine, methionine, isoleucine, phenylalanine, tryptophane, and tyrosine. The amino acids subject to investigation and confirmation, or present in minimal amounts were *beta*-alinine and two distinct amino acids near the position occupied by proline on the paper chromatogram. The two last-mentioned substances were previously observed by Dent in animal material and therefore seem to be of general distribution in nature. There was a preponderance of isoleucine over leucine (the latter was not definitely found), cystine and methionine were not so conspicuous as expected, hydroxyproline was not positively detected, and *alpha*-amino-n-butyric acid was present only in traces. It is believed that the last-named acid is a break-down product of an amino acid, rather than an intermediate of protein synthesis, since its presence was previously claimed in blood and urine (3).

In 1949, Steward, Thompson and Dent (16) reported the detection of *gamma*-amino-butyric acid as a component of the free amino acids of the potato. This acid accounted for 5 per cent of the alcohol soluble N and 3.7 per cent of the total N of the Katahdin potatoes examined. This acid does not occur in the protein hydrolyzate but is used by potato cells in protein synthesis.

Zacharius, Thompson, and Steward (21) recently reported the occurrence in fresh green beans, and probable occurrence in potatoes and mushrooms, of *levo*-pipecolic acid. This is piperidine 2-carboxylic acid — or the 6-membered ring homologue of proline.

The Proteins

Before the turn of the century, Osborne and Campbell (11) isolated a globulin, which they named tuberin, in expressed potato juice. Another protein fraction was isolated from the residual pulp by extraction with sodium chloride solution. Since these proteins had similar elementary compositions, similar precipitation limits with $(NH_4)_2SO_4$, and seemingly comparable heat coagulation behavior, these workers considered them to be identical. Fifty years later (1946) Groot and coworkers (6) in Amsterdam found that Osborne's tuberin was actually a mixture of two proteins, which could be separated by electrophoresis, by precipitation at different pH values, and by fractional precipitation with $(NH_4)_2SO_4$. For the protein precipitated at the lower pH, they sugggested the name "tuberinin," and retained the name "tuberin" for the other protein. The

ratio of tuberin to tuberinin was 71/29. However, Jirgensons (8) suggests that owing to the labile nature of proteins in potato juice, several different proteins can be separated, depending on the methods employed. Furthermore, it should be borne in mind that the number of proteins will be dependent on the system of classification. For example, each enzyme system involves a separate and distinct protein.

Several years ago Chick and Slack (2) reported the isolation of *alpha*- and *beta*-globulin from potato press juice. In freshly dug potatoes, the ratio of *alpha* and *beta* was 1 to 2; in a sample of stored potatoes it was 2 to 1.

When we consider that the potato is in reality a well-stocked reservoir of free amino acids, enzyme systems, labile proteins, carbohydrates, and metabolically important amides, we can better appreciate its behavior. Possibilities for numerous and varied reactions are provided. Unfortunately, many of these reactions are of an undesirable nature and lead to discoloration and deterioration in handling, storing, and processing. When we accumulate more of the basic knowledge of all the constituents, we shall be in a position to control these undesirable changes.

Nutritional Studies

The nutritional value of the amino acids and proteins is of particular interest to the potato industry. As a result of several recently completed studies, we are now in a better position to appreciate and interpret nutritional data. In the words of Thompson (18): "When you can measure what you are speaking about, and express it in numbers, you know something about it, but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind."

Our present ability to express numerically the nutritional value of the amino acids and proteins of the potato is derived from the classic works of Chick and Slack (2) in England, Groot (5) in Holland, and Steward (17) and Rose (13) in this country.

The fact that the nitrogen of the potato, weight for weight, is as efficient as that of wheat and closely approximates casein, for maintenance of nitrogenous equilibrium in adult man or animals, has been abundantly demonstrated. Three years ago Chick and Slack wrote about this as follows: "The reason why this should be so, seeing that 50 per cent or more of the potato nitrogen is non-protein in nature, puzzled Rubner 70 years ago. The puzzle remains unsolved, in spite of the advances in knowledge of proteins and nutrition which have been achieved since the period when Rubner was confronted with it."

Chick and Slack have made comparative studies of the nutritive value of the fractions shown in table 2 with that of the whole potato on an equivalent nitrogen basis. What they actually compared was the protein fraction, the non-protein nitrogen fraction, a mixture of these two in the ratio of their occurrence in the potato, and the whole potato. The nutritive values were judged by the capacity to support the growth of weanling rats. They found that on the basis of nitrogen content, the nutritive value of their tuberin was not superior to that of the mixture of protein and non-protein nitrogenous material in the whole potato. The non-protein nitrogen in the press-juice, after removal of the tuberin, was unable to support growth, but when combined with tuberin in the proportions in

TABLE 2.—*Amino-acid-content of potato sap.*

(g./16 g. N)

	(1) Tuberin Fraction	(2) N. P. N. Fraction	(3) 53 Parts (1) + 47 " (2) *
Phenylalanine	6.6	4.1	5.4
Leucines	17.5	4.3	11.3
Valine	6.1	3.3	4.8
Tryptophan	1.6	—	0.8
Threonine	5.9	1.1	3.7
Arginine	6.0	2.6	4.4
Histidine	2.2	1.1	1.7
Lysine	7.7	1.9	5.0
Cystine	2.1	1.2	1.6
Methionine	2.3	0.8	1.6

*The proportions in which the protein and N.P.N. were present in the sample of potatoes used. (Ref. 2).

which non-protein and protein nitrogen exist in the whole potato, the nutritive effect between the tuberin and protein-free fraction of the press although still inferior to that of the nitrogenous mixture *in situ* in the intact tuber. This result shows a complimentary nutritive action between the protein and the non-protein nitrogen in the potato. The supplementary nutritive effect between the tuberin and protein-free fraction of the press juice could not be explained on the basis of their amino acid contents. The tuberin fraction was richer in all essential amino acids than was the non-protein nitrogen fraction as shown in table 2.

What can be said of the quality of these nitrogenous constituents with regard to human nutritional requirements? Because of recently completed nutritional investigations by Rose and collaborators (13), we are now in a position to calculate the value of these nitrogen components. These tests were made on a comparatively large number of healthy male graduate students during the last 10 years. It was shown qualitatively that man requires only the eight amino acids shown in column 1 of table 3, when sufficient nitrogen is available in the diet for synthesis of the non-essential amino acids. Histidine, which is indispensable for the rat, and arginine, which is necessary for its minimum growth, are not required for the maintenance of nitrogen equilibrium in normal human adults.

The smallest amount of each of the eight essential amino acids that would maintain human nitrogen equilibrium was also determined. The minimum daily requirement of each is shown in column 2 of table 3. In other words, adults require the indicated amount of the respective amino acids for the maintenance of health. A safety factor is provided in that the recommended daily intake, shown in column 3, is twice the minimum requirement.

A word of caution is also supplied by Rose: "Discussion has been limited to the indispensable amino acids. This emphasis should not lead to the impression that the so-called non-essentials possess little significance.

TABLE 3.—*Minimum and recommended intakes of the essential amino acids for normal man.*

(When the diet furnishes sufficient nitrogen for the synthesis of the non-essentials.)

Amino Acid	Minimum Daily Requirements, Grams	Recommended Daily Intake, Grams	Number of Subjects Tested
L—Tryptophan	0.25	0.5	37**
L—Phenylalanine	1.10	2.2	28
L—Lysine	0.80	1.6	33
L—Threonine	0.50	1.0	24
L—Valine	0.80	1.6	29
L—Methionine	1.10	2.2	19
L—Leucine	1.10	2.2	14
L—Isoleucine	0.70	1.4	14

**Thirty three were kept in balance on 0.3 gram or less.

As a matter of fact, all exist as tissue components, even though they may be excluded from the food."

In view of the results of Chick and Slack and of Rose, we can now appreciate the nutritional value of the free amino acids in potato juice. The quantitative data on these essential amino acids permits calculations that should be of interest to all. For example, how much of the minimum daily requirements of the eight essential amino acids is supplied by potatoes? On the basis of the annual *per capita* consumption in the U. S. of 104 pounds, an average of 130 grams is eaten daily. This ration contains about 0.4 gram of nitrogen and on the basis of Chick and Slack's analytical studies, which are largely confirmed by Groot (5), Steward (17), and Hirsch (7), contains the calculated amounts of amino acids shown in column 2 of table 4.

TABLE 4.—*Essential amino acids supplied by average daily ration of potatoes.*

Amino Acid	Amount in 130 Gms. Whole Potatoes, Grams	Minimum Daily Requirements, Grams	Per cent Minimum Daily Requirement
L—Tryptophan	0.02	0.25	8
L—Phenylalanine	0.135	1.10	12
L—Lysine	0.125	0.80	16
L—Threonine	0.093	0.50	18
L—Valine	0.120	0.80	15
L—Methionine	0.05	1.10	4-5
L—Leucine	0.115	1.10	14
L—Isoleucine	0.093	0.70	13

Dividing each value by the minimum daily requirement shown in column 3 gives column 4, the approximate percentages of our minimum daily requirements of essential amino acid supplied by potatoes on a *per capita* consumption basis. You will note that these figures are 8

per cent for tryptophane, 12 for phenylalanine, 16 for lysine, 18 for threonine, 15 for valine, 4-5 for methionine, 14 for leucine, and 13 for isoleucine. It should be borne in mind that this calculation is only approximate and that twice the minimum requirement is recommended for daily consumption.

In six European countries, the annual *per capita* consumption of potatoes during the period 1934-1938 (as reported by Yates (20)) was

	Pounds
Switzerland	198
Great Britain	210
Denmark	246
Germany	398
France	400
Belgium	440

These data indicate that in Belgium, France, and Germany potatoes supplied approximately the following percentages of the minimum daily requirements of essential amino acids.

	Per cent
Tryptophane	32
Phenylalanine	48
Lysine	64
Threonine	72
Valine	60
Methionine	16-20
Leucine	56
Isoleucine	52

A further check on the validity of this type of calculation is afforded by the data of Kon and Klein (9), which showed that human adults were maintained in nitrogen balance and in good health for as long as 5 months on diets that included potatoes as the only source of nitrogen. For an adult man, the daily consumption of potatoes was slightly less than 4 pounds, which furnished about 5.7 grams of nitrogen. This quantity of nitrogen is 14.2 times the value employed in calculating the percentages in the last column of table 4. Accordingly, multiplication of the latter percentages by 14.2 should yield percentages equal to or greater than 100 per cent. This was found to be true except in the case of methionine. Varietal differences in amino acid composition (17) or difficulties in the methionine assay might possibly account for this discrepancy.

These calculations are based on analyses of raw potatoes. Comparable analytical data on stored and cooked potatoes would be more pertinent. Nevertheless, the calculations demonstrate emphatically that in addition to carbohydrates potatoes contain appreciable amounts of the amino acids essential to man.

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OBSERVATIONS ON THE EFFECTIVENESS OF DDT, PARATHION, AND MALATHON AGAINST THE IRIS WHITEFLY ON POTATOES[1]

B. J. LANDIS AND K. E. GIBSON[2]

The iris whitefly (*Aleyrodes spiraeoides* Quaint.) infests potatoes in parts of Washington, Oregon, and Idaho. In central Washington it is often the most abundant, if not the most destructive, insect pest of the fall crop. Preliminary observations (Gibson and Landis 1950) indicated that several chlorinated hydrocarbon insecticides, particularly DDT, were partially effective against the adults of this whitefly but not against the immature stages. Additional observations on the relative effectiveness of DDT, parathion, and malathon dusts and sprays that were applied primarily for the control of the green peach aphid (*Myzus persicae* (Sulz.)) were made in central Washington from 1949 to 1952.

Methods — The tests in Yakima and Benton Counties were conducted in 1 White Rose and 10 Netted Gem (Russet Burbank) potato fields.

The insecticides were applied either with a power crop duster or by aircraft. Plots ranged from 8 to 48 rows in width and from 200 to 1,200 feet in length. Treatments were arranged in a randomized block design with three or four replicates where aircraft was used and four to eight where ground equipment was used exclusively. Either four or five applications were made in each field. Applications with the crop duster were made at 25 pounds per acre except in fields 7 and 11, where the dosage ranged from 25 to 30 pounds. Applications by aircraft were at the rate of 30 pounds of dust and 4½ gallons of spray per acre in field 7, and 23 pounds of dust and 4¼ to 4½ gallons of spray in field 10.

Infestations of the iris whitefly were recorded as the number of leaves found with various stages of the insect in periodic collections of 50 compound leaves per plot, except in unusually large plots where 150 leaves were taken. The plots were sampled 7 days after each application, and also at 2-week intervals after dusting or spraying was stopped until harvest or frost. From the plots of fields 4 to 11 samples were taken also 1 day before and 3 days after each application.

In Kittitas County, where insecticide applications were made to entire fields of potatoes by aircraft, 50-leaf samples were collected from each field during the week preceding application and twice at approximately weekly intervals after application.

TESTS IN 1949

Except for a sodium fluoaluminate dust without added toxicants, which was applied primarily for the control of chewing insects, all dusts contained either DDT or parathion, or both (table 1). A non-volatile oil

[1]Accepted for publication June 16, 1953.
In cooperation with the Washington State Department of Agriculture and the Washington Agricultural Experiment Stations. James Watson and John R. Catlin assisted with the work in Kittitas County.

[2]Bureau of Entomology and Plant Quarantine, Agricultural Research Administration, United States Department of Agriculture, Yakima, Wash.

TABLE 1.—*Effectiveness of various insecticide dusts in controlling the iris whitefly in 1949.*

Insecticide (Per cent by Weight)	Pounds of Toxicant[1] per Acre	Leaves Infested per 1,000					
		With Eggs		With Larvae-Pupae		With All Stages	
		During Dusting	After Dusting	During Dusting	After Dusting	During Dusting	After Dusting
Field 1 (Early crop)							
DDT:							
5	5.1	trace	5	0	10	trace	14
5 + oil 2	4.9	0	5	0	12	0	15
3 + oil 2	3.2	0	7	trace	12	trace	16
5 + parathion 0.5	4.9 + 0.5	0	13	0	17	0	28
Parathion:							
0.5	0.5	0	11	0	43	0	54
1	0.9	0	5	0	25	0	29
Difference required for significance at odds of 19 to 1		2	2	2	11	2	16
Field 2 (Early crop)							
DDT:							
5	4.8	0	5	0	13	0	19
4 + sulfur 80	3.6	0	30	0	35	trace	65
5 + sulfur 75	5.1	0	23	0	24	0	45
Sodium fluoaluminate:							
33.3	32.2	2	18	4	60	6	80
33.3 + parathion 0.5	33.8 + 0.5	0	19	3	40	trace	52
Difference required for significance at odds of 19 to 1		1	2	2	15	2	21
Field 3 (Late crop)							
DDT:							
5	4.6	6	1	0	0	6	1
5 + oil 2	4.9	6	0	0	1	6	1
3 + oil 2	2.9	4	3	1	1	5	4
4 + sulfur 80	3.6	9	0	0	0	9	0
5 + sulfur 75	4.7	6	0	trace	1	7	3
5 + parathion 0.5	4.7 + 0.5	6	0	trace	0	7	0
Sodium fluoaluminate:							
33.3	30.3	19	0	5	28	24	29
33.3 + parathion 0.5	29.7 + 0.4	11	0	1	10	13	11
Parathion:							
0.5	0.5	8	0	0	15	9	16
1	0.9	11	0	0	4	12	8
Difference required for significance at odds of 19 to 1		2	2	2	8	10	9

[1]Sulfur not included in these figures.
[2]Not significant by the *F* test.

was added to two of the DDT dusts. The DDT dust containing 80 per cent of sulfur was a proprietary product prepared by fusing the ingredients and regrinding them to 325-mesh particle size. The DDT dust containing 75 per cent sulfur, also used in 1950, was a proprietary mixture containing both dusting sulfur and a reground mixture of bentonite and sulfur. All laboratory-mixed dusts contained pyrophyllite as the diluent except one used in 1951, which contained talc.

Four applications were made in each field — from May 18 to June 29 in field 1, from May 13 to July 2 in field 2, and from July 25 to September 2 in field 3. Dusting was stopped when the plant growth closed the space between the rows, but since sampling was continued for several weeks the infestation data were compiled until the end of the growing season.

In the early-crop fields infestations developed during the dusting period, but increased appreciably after dusting ceased. In the late-crop field large numbers of eggs were deposited during the dusting period, but oviposition declined about the time that dusting was stopped. The sodium fluoaluminate dust apparently deterred some egg laying in the early-crop field during the dusting period, but was much inferior to the DDT or parathion dusts in preventing larval development. Although both DDT and parathion kept the infestations far below the level at which damage occurred during the periods of treatment, parathion allowed a rapid buildup after dusting was stopped. In these tests the addition of oil, sulfur, or parathion to DDT was of no apparent benefit and in some cases resulted in poorer control.

Tests in 1950

Field 4 was dusted five times from May 18 to July 7, field 5 three times from May 19 to June 19, and field 6 three times from July 18 to August 25 as shown in table 2. The whitefly was more abundant than in 1949 and, although DDT was used in all the dusts, large numbers of eggs were deposited, particularly on the late crop. The tests with 10 per cent of DDT showed a considerable improvement over the 5 per cent dust used in 1949.

In some tests the addition of sulfur to the DDT dust improved control, particularly of the larvae and pupae. This improvement was due either to the use of sulfur of a finer particle size than in 1949 or to the improved dusting quality of the mixture. The addition of parathion to the sulfur dust containing 5 per cent of DDT was of little value on the early crop, since it did not extend the period of residual toxicity of the DDT, but on the late crop, where dusting was continued until egg laying had nearly ceased, the mixture gave control equal to that of sulfur dust containing 10 per cent of DDT.

Tests in 1951

In field 7 the effectiveness of five applications of a proprietary dust containing 5 per cent of DDT, 0.5 per cent of parathion, and 45 per cent of sulfur, applied by both ground equipment and aircraft, and of an emulsion spray containing 4 per cent of DDT plus 0.4 per cent of

TABLE 2.—*Effectiveness of various insecticide dusts in controlling the iris whitefly in 1950.*

Insecticide Per cent by Weight	Pounds of Toxicant[1] per Acre	Leaves Infested per 1,000					
		With Eggs		With Larvae-pupae		With All Stages	
		During Dusting	After Dusting	During Dusting	After Dusting	During Dusting	After Dusting
		Field 4 (Early Crop)					
DDT:							
5	6.3	3	24	3	22	7	48
5 + sulfur 50[2]	6.2	3	30	trace	23	3	49
5 + sulfur 50[3]	6.8	1	26	1	24	2	47
5 + sulfur 50[2] + parathion 0.5	6.3 + 0.6	2	37	0	16	2	49
5 + sulfur 75[3]	6.7	2	23	0	19	2	40
10 + sulfur 50[2]	13.4	trace	10	trace	18	trace	28
Difference required for significance at odds of 19 to 1		4	16	1	5	3	4
		Field 5 (Early crop)					
DDT:							
5	3.5	8	33	3	19	11	53
5 + sulfur 50[2]	3.5	2	13	2	13	4	24
5 + sulfur 50[3]	4.0	9	20	0	11	9	31
5 + sulfur 50[2] + parathion 0.5	3.5 + 0.4	6	27	trace	8	7	33
5 + sulfur 75[3]	3.8	8	29	2	15	9	43
10 + sulfur 50[2]	7.4	4	10	trace	3	5	13
Difference required for significance at odds of 19 to 1		4	4	4	4	4	4
		Field 6 (Late crop)					
DDT:							
5	3.7	21	2	11	18	31	22
5 + sulfur 50[2]	3.6	15	2	4	17	20	15
5 + sulfur 50[3]	3.5	12	0	3	8	14	8
5 + sulfur 50[2] + parathion 0.5	3.6 + 0.4	11	0	9	2	19	2
5 + sulfur 75[3]	3.6	11	0	6	12	17	12
10 + sulfur 50[2]	7.4	6	0	2	2	8	2
Difference required for significance at odds of 19 to 1		4	4	4	12	4	12

[1]Sulfur is not included in these figures.
[2]3-mu, wettable sulfur.
[3]325-mesh, sulfur-bentonite mixture.
[4]Not significant by the *F* test.

parathion applied by aircraft was compared. Applications were made between May 22 and August 8. In fields 8 and 9 four applications of six different dusts were made with ground equipment between June 18 and August 29. Since dusting in all three fields was continued until near harvest time, or after the seasonal decline of whitefly populations, the infestation data are presented as seasonal totals.

In field 7 the DDT-parathion-sulfur dust was more effective in preventing egg laying when applied with the crop duster than by aircraft, and this method was also superior to aerial applications of the dust or the spray in preventing larval-pupal infestations from developing as you will note in table 3. In fields 8 and 9 better control was obtained by adding sulfur to the DDT dust, although, the results were erratic. The

TABLE 3.—*Effectiveness of various insecticide dusts and a spray in controlling the iris whitefly in 1951.*

Insecticide (Per cent by Weight)	Pounds of Toxicant[1] per Acre	Leaves Infested per 1,000		
		With Eggs	With Larvae and Pupae	With All Stages
		Field 7 (Early crop)		
DDT				
5 + sulfur 45 + parathion 0.5 (dust)				
Applied by Aircraft	7.5 + 0.8	198	255	348
Applied by Crop duster	7.2 + 0.7	88	85	161
4 + parathion 0.4 (spray)				
Applied by aircraft	7.5 + 0.8	120	151	243
Difference required for significance at odds of 99 to 1		39	75	39
		Field 8 (Late crop)		
DDT:				
5 + pyrophyllite	5.8	131	139	242
5 + sulfur 12.5 + pyrophyllite	6.1	106	140	218
5 + sulfur 25 + pyrophyllite	6.2	101	119	198
5 + sulfur 50 + pyrophyllite	6.0	127	121	218
5 + sulfur 50 + talc	6.3	119	106	207
5 + sulfur 50 + parathion 0.5 + pyrophyllite	5.7 + 0.6	102	91	168
Difference required for significance at odds of 19 to 1		2	2	2
		Field 9 (Late crop)		
DDT:				
5 + pyrophyllite	5.5	157	194	307
5 + sulfur 12.5 + pyrophyllite	5.4	148	173	292
5 + sulfur 25 + pyrophyllite	5.9	156	192	317
5 + sulfur 50 + pyrophyllite	6.0	141	141	256
5 + sulfur 50 + parathion 0.5 + pyrophyllite	5.3 + 0.5	146	115	234
Difference required for significance at odds of 19 to 1		2	44	52

[1]Sulfur is not included in these figures.
[2]Not significant by the *F* test.

dusts containing the highest percentages of sulfur showed the most promise in the control of the larvae and pupae. The addition of 0.5 per cent of parathion to the DDT—sulfur dusts also improved the control somewhat, particularly of the larvae and pupae in field 9.

Tests in 1952

Four applications of dusts and sprays were made by aircraft from May 17 to July 9 in field 10, and four applications of dusts with a crop duster from August 19 to September 22 in field 11 (Table 4).

In field 10 the malathon dusts and sprays gave relatively poor control of the whitefly, and the 5 per cent dust was much inferior to the emulsion spray. Though the difference was not significant, the emulsion spray containing 4 per cent of DDT plus 0.64 per cent of parathion and the oil spray containing 4.5 per cent of DDT tended to be superior to the DDT-parathion-sulfur dust mixture.

Table 4.—*Effectiveness of various insecticide dusts and sprays in controlling the iris whitefly in 1952.*

Insecticide (Per cent by Weight)	Pounds of Toxicant[1] per Acre	Leaves Infested per 1,000		
		With Eggs	With Larvae and Pupae	With All Stages
		Field 10 (Early crop)		
DDT (applied by aircraft):				
5 + sulfur 15 + parathion 0.44 (dust)	4.6 + 0.4	14	4	18
4 + parathion 0.64 (spray)	6.1 + 1.0	5	1	7
4.5 + oil (spray)	6.1	6	trace	6
Malathon (applied by aircraft):				
5 (dust)	4.7	22	12	33
1.66 (spray)	2.5	11	2	13
Difference required for significance at odds of 19 to 1		11	3	12
		Field 11 (Late crop)		
DDT (applied with ground equipment):				
5 + parathion 0.5 (dust)	6.2 + 0.6	10	2	11
5 + sulfur 5 + parathion 0.5 (dust)	5.4 + 0.5	7	1	8
5 + sulfur 10 + parathion 0.5 (dust)	5.8 + 0.6	18	7	23
5 + sulfur 50 + parathion 0.5 (dust)	5.4 + 0.5	12	3	14
Malathon (applied with ground equipment):				
5 (dust)	5.3	22	2	23
Difference required for significance at odds of 99 to 1		10	2	12

[1]Sulfur is not included in these figures.
[2]Not significant by the *F* test.

In field 11, which was planted July 20, the 5 per cent malathon dust again gave relatively poor control of the whitefly. It was inferior to the low-sulfur DDT-parathion dusts in preventing egg laying and not significantly better than these dusts in controlling the larvae and pupae.

Tests with Single Applications

The effectiveness of single aerial applications of four dusts and three sprays in reducing whitefly infestations during the first and second weeks after each application was observed in Kittitas County in 1951 and 1952. Unlike the tests in Yakima County, the treatments were commercial applications made after heavy infestations had developed. Under these conditions none of the treatments gave satisfactory control as shown

TABLE 5.—*Effectiveness of single aerial applications of various insecticide dusts and sprays in controlling the iris whitefly in 1951 and 1952.*

Insecticide (Per cent by Weight)	Dosage per Acre	Number of Replicates	Insect Stage	Number of Leaves Infested per 50 before Treatment	Per cent Change in Infestation	
					First Week	Second Week
Dusts:	Pounds					
DDT:						
5	20	20	Eggs	35	— 0.6	—12.7
			Larvae-pupae	40	7.4	8.4
			All stages	46	2.6	3.3
5 + parathion 1	20	7	Eggs	38	—15.1	—20.3
			Larvae-pupae	41	3.2	7.6
			All stages	46	— 1.1	— 3.2
5 + parathion 1 + sulfur 50	20	4	Eggs	41	0.7	—11.4
			Larvae-pupae	34	— 5.2	11.7
			All stages	46	— 1.5	— 8.8
Parathion:						
1	20	6	Eggs	36	—18.8	— 5.6
			Larvae-pupae	37	19.7	21.1
			All stages	45	2.0	5.6
Sprays:	Gallons					
DDT in oil 4.5	3	4	Eggs	27	20.0	5.7
			Larvae-pupae	12	89.6	91.3
			All stages	29	25.9	35.5
	4	4	Eggs	41	8.5	—24.9
			Larvae-pupae	38	30.4	21.7
			All stages	46	8.3	0.2
DDT 4 + parathion 0.64 (emulsion)	4½	10	Eggs	32	—30.9	—23.6
			Larvae-pupae	35	— 1.7	7.4
			All stages	43	—10.1	— 4.4

in table 5. Parathion, alone or in combination with DDT, gave the best control of the adult whiteflies, and provided the most rapid reduction of egg infestations, but infestations increased during the second week where DDT was lacking in the treatment. The best control after 2 weeks was obtained with DDT plus parathion, and the low-gallonage emulsion spray containing these insecticides was superior to all other treatments.

Summary

In central Washington the iris whitefly (*Aleyrodes spiraeoides* Quaint.) often causes damage to the late crop of potatoes, but it is of minor importance as a pest of the early crop. During tests that were made primarily for the control of the green peach aphid from 1949 to 1952, the effectiveness of various insecticide dusts and sprays for control of the whitefly was also observed.

DDT, parathion, and malathon were tested separately; mixtures of DDT with oil or sulfur, and DDT-parathion-sulfur mixtures also were tried. Dusts applied with ground equipment gave better control than those applied by aircraft. Sprays gave better control than dusts, when applied by aircraft.

Dusts and sprays that contained DDT reduced infestations slowly, but delayed reinfestation of the plants for a longer time than did either parathion or malathon. In this respect a 10 per cent dust was superior to a 5 per cent. An oil spray that contained 4.5 per cent of DDT was particularly slow in reducing established infestations, but repeated applications gave good control throughout the season. No improvement in control was observed when 2 per cent of oil was added to the DDT dusts. The addition of 5 to 80 per cent of sulfur to the DDT dusts did not further reduce egg laying but improved the control of the larvae and pupae in some tests. Malathon, either as a 5 per cent dust or as a 1.66 per cent spray, gave poor control. Dusts containing 1 per cent of parathion were more effective than DDT in reducing egg laying the first week after application, but they were of only temporary value.

All the treatments gave temporary control of the adults, and repeated applications either prevented establishment of larval infestations or reduced them to less than damaging levels. Although DDT alone kept whitefly infestations from developing when applications were started early in the period of plant growth, where infestations were allowed to develop prior to treatment a mixture of DDT and parathion was required. Aerial applications of an emulsion spray containing 4 per cent of DDT plus 0.64 per cent of parathion gave better control than a dust containing 5 per cent of DDT plus 1 per cent of parathion, and both were superior to a 5 per cent DDT dust.

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THE BOX AS A CONTAINER FOR POTATOES[1]

R. B. HOPKINS[2]

Our usual system of harvesting potatoes in Maine consists of several operations each of which causes mechanical injuries. All tubers are picked by hand into a basket which is emptied into a barrel. The barrels are then trucked to a storage and the contents emptied into a bin.

A survey of handling methods was made by Schrumpf (2) in 1931 and 1932. He reported that emptying the contents of picking baskets into barrels injured 8.16 per cent by weight of the tubers whereas an additional 19.12 per cent were injured when the potatoes were placed in bulk storage. The movement of the potatoes from the bin to the grader after storage further injured 13.27 per cent of the tubers.

When potatoes are picked from the ground into boxes and the box is used as a storage container the operations of emptying baskets into barrels and emptying barrels into storage are eliminated. For several years the potatoes were handled and stored in boxes at Aroostook Farm of the Maine Agricultural Experiment Station. Edgar (1) reported on a comparison of the use of boxes to the conventional method of barrel handling and bulk storage. The use of boxes resulted in an increase from 64.9 per cent to 72.7 per cent of the potatoes meeting Fancy grade which he attributed to a reduction of grade injuries from handling operations. However, considerably more labor was required to stack the boxes in the storage than to fill bulk bins. In addition, there was a somewhat higher shrinkage rate in the boxed potatoes as well as a reduction of storage capacity through the use of boxes.

When a program of potato handling research was undertaken by the Maine Agricultural Experiment Station the previous experiences with box-handled potatoes led to a further study of the subject. The boxes used are similar to apple boxes in construction with a capacity of approximately 60 pounds of potatoes. In 1950 Katahdins were picked from the ground into boxes and placed in storage. Of the 200 boxes filled, ten were selected at random for examination by a Federal-State Inspector who classified the contents into the following groups:

1. Culls — all tubers under 1½ inch in diameter and all larger tubers which would be disqualified from U. S. No. 1 grade because of defects other than mechanical injuries. Some examples of such defects are sunburn, growth cracks and rot.

2. Major Injury — tubers which were disqualified from U. S. No. 1 grade because of mechanical injuries.

3. Minor Injury — tubers with mechanical injuries which penetrated the flesh but were not sufficiently serious to disqualify the tubers from U. S. No. 1 grade.

4. Uninjured — U. S. No. 1 tubers without mechanical injuries.

The boxes whose contents had been examined were distributed throughout the pile as they were stacked in the farm storage. After approximately 120 days the potatoes were removed from storage and the

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sample boxes were re-examined by the same inspector. The potatoes were graded, washed and weighed to determine the percentages of U. S. No. 1's and culls.

In 1951 a direct comparison of box and bulk storage was undertaken. Two adjoining bins, each 10 feet x 6½ feet x 14 feet deep were selected to obtain comparable conditions in each bin. All potatoes were dug from one field with the same digger. The bulk-stored potatoes were picked by hand into baskets which were emptied into unpadded barrels. At the storage the barrels were emptied and the potatoes conveyed to a canvas chute containing baffles through which they dropped into the bin. As the bin was filled six boxes containing known weights of field run potatoes were placed at three levels near the center of the bin. Vertically, the boxes were located near the bottom, at the center and near the top of the bin. A thermocouple was fastened to each box in order that temperatures during storage might be obtained.

The boxes were filled from picking baskets because partially filled boxes are difficult to move along the row. Twenty-three samples were selected at random from a total of 272 boxes. The samples were examined by the same inspector as in the previous year. As the boxes were stacked 12 high in the bin the samples were distributed throughout the pile. Thermocouples were placed near the center and top of the bin in locations comparable to the bulk-stored bin. An inadequate supply of thermocouple wire prevented the placing of thermocouples in the bottom of the bin and also prevented the taking of temperature readings in either bin for approximately the first month of storage. Temperature readings were then taken in both bins at intervals of about one week.

After a storage period of approximately 160 days the bins were emptied. The contents of the boxes buried in the bulk bin were re-weighed for shrinkage determinations. The sample boxes in the box-stored lot were re-examined by the same inspector. The contents of the bins were graded, washed and weighed to determine the percentages of U. S. No. 1's and culls. While the bulk bin was being emptied ten samples were selected and examined for injuries. A comparison with the box-stored samples indicates that there was no significant difference in the extent of either minor or major injuries between the two methods.

In table 1 the observed shrinkage rates for the two storage methods are presented. The shrinkage of bulk-stored potatoes during the 1950-1951 season was obtained from sample boxes which were buried in bins for another experiment. These data indicate a higher shrinkage rate for the box-stored potatoes. Edgar (1) concluded that the shrinkage loss of stored potatoes is dependent upon the length of storage period, average saturation deficit (difference in vapor pressure of air of a given temperature at (a) 100 per cent relative humidity and (b) at the actual relative humidity) and the curing temperature for the first two weeks. His studies indicated that a curing temperature of 56° to 60° F is desirable. Werner (3) stated: "Effective wound healing does not occur at a temperature below 55° F., and takes place slowly and incompletely if the relative humidity is below 75 per cent."

Unfortunately, temperature records could not be obtained during the first month of storage in the second season. However, the rate of temperature decline after observations were begun indicates that the

temperatures in the boxed bin may have been too low during the curing period for the injured areas to suberize completely. Observations in other bulk bins within the same storage during the 1951-1952 season revealed significantly more shrinkage where the tubers were stored near an outside wall and may have cooled more rapidly during the curing period. However, the correlation between temperatures during the period of observation and shrinkage was not statistically significant. In table 2 the temperatures from the two storage methods indicate that the mean temperature was lower in the box-stored bin than in comparable portions of the bulk bin. There also was less difference in temperature between the center and top portions of the box-stored bin than in the bulk bins. Although there was no forced ventilation in the storage, more air movement may have occurred through the boxed potatoes because of the voids between boxes. In addition, there was less than one-half the weight of potatoes in the boxed bin as in the bulk bin which probably resulted in less heat being released from respiration. This in turn would tend to cause lower temperatures.

TABLE 1.—*Comparison of shrinkage rates for box and bulk-stored potatoes.*

Stored In	Season	Time Held Days	Shrinkage Per cent
Box	1950-51	125	4.4
Bulk	1950-51	160	4.6
Box	1951-52	175	5.5
Bulk	1951-52	175	2.8

TABLE 2.—*Comparison of mean temperatures for storage methods during 1951-1952 season.*

Location in Bin	Temperature °F.	
	Box-Stored	Bulk-Stored
Top	45.6	47.0
Center	44.7	45.3
Bottom	——	44.5

In table 3 the results of grading potatoes handled by the two methods are presented. The results from the 1950-1951 season probably do not represent the differences as well as the results from the 1951-1952 season. The box-stored potatoes yielded a slightly higher percentage of marketed potatoes than did the bulk-stored. There were greater differences in favor of the box-stored potatoes when they were washed rather than unwashed.

Schrumpf (2) reported in 1933 that major injuries increased from 7.10 per cent at the time of storage to 9.65 per cent at the end of a 59 day storage period. He attributed the increase in major injuries

to the drying out of the damaged tissues and the entry of decay organisms into minor injuries. In this investigation sample boxes were examined each season before and after storage to determine if changes occurred during storage. Table 4 presents a summary of the results. Analyses of variance of the 1950-1951 data revealed that the decreases in major injuries was not significant, the increase in minor injuries was highly significant and the decrease in culls was significant. Similar analyses of the 1951-1952 data indicated that the decrease in major injuries was significant and the increase in minor injuries was highly significant. The highly significant increases in minor injuries each season were not unexpected because small injuries are more easily detected after they have dried out for a period of time. The significant decreases in major injuries in the 1951-1952 season and of culls in the 1950-1951 season are difficult to explain. In the 1950-1951 season the boxes were stored in a location where some of the tubers turned green from exposure to artificial light. In the inspection of the samples an attempt was made to ignore the effect of light exposure. Sunburn on some tubers may have been obscured by the greening during storage.

TABLE 3.—*Yields of marketed potatoes from different storage methods.*

Stored In	Season	U. S. No. 1's — Per cent[1]	
		Unwashed	Washed
Box	1950-51	90.5	87.7
Bulk[2]	1950-51	86.7	—
Box	1951-52	96.9	95.5
Bulk	1951-52	96.3	94.1
Bulk[3]	1951-52	94.7	92.6

[1]In 1950-1951, per cent of potatoes between 2¼ in. and 3¾ in. packaged as U. S. No. 1; in 1951-1952 per cent between 1⅞ in. and 4 in. Remainder were discarded as culls.
[2]Other potatoes from the same farm; exact handling procedure not known.
[3]Other potatoes from the same field, handled in the same manner as bulk potatoes in this study.

TABLE 4.—*Change in status of tubers during storage.*

	1950-1951 Season			1951-1952 Season		
	Before Storage Per cent by Weight	After Storage Per cent by Weight	Change[1]	Before Storage Per cent by Weight	After Storage Per cent by Weight	Change[1]
Uninjured	78.3	68.0	—10.3	79.8	60.6	—19.2
Major Injuries	0.5	0.4	— 0.1	1.1	0.2	— 0.9
Minor Injuries	8.7	27.9	19.2	9.1	29.0	19.9
Culls	12.5	3.7	— 8.8	10.0	10.2	0.2
TOTAL	100.0	100.0		100.0	100.0	

[1]Negative change represents decrease, positive change represents increase.

The lack of standards for the measurement of appearance makes it difficult to make any such comparisons. However, the box-stored potatoes were noticeably brighter and cleaner in appearance than the bulk-stored potatoes.

Edgar (1) published data indicating that box storage required considerably more labor than bulk storage. Apparently, much of the additional labor was required for stacking the boxes. A reduction of labor might be obtained by handling the boxes in the storage with a fork lift truck. This would however, preclude the use of basement bins to which there is no access by vehicles at the level of the bin floor.

Summary

The use of boxes as a container for the handling and storage of the Katahdin variety of potatoes has been compared with the conventional method of barrel handling and bulk storage.

There was a higher shrinkage rate in the boxed potatoes than in the bulk-stored potatoes. This was probably due to incomplete suberization of the injured areas resulting from too rapid cooling during the curing period.

The box-stored potatoes cooled more rapidly and maintained lower temperatures than bulk stored potatoes in corresponding portions of the bin.

The box-stored potatoes yielded a slightly higher percentage of U. S. No. 1's than did the bulk-stored. The difference between box and bulk stored was slightly greater when the potatoes were washed rather than unwashed.

At the conclusion of the storage period there were no significant differences in the extent of mechanical injuries resulting from the two handling methods. During the storage period the percentage of tubers on which minor injuries could be detected increased more than three times.

At the conclusion of the storage period the boxed potatoes possessed a somewhat brighter, cleaner appearance than the bulk stored.

The hand stacking of boxes requires an excessive amount of labor which might be reduced by handling boxes with a fork lift truck.

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POTATO NEWS AND REVIEWS

THE GOLDEN NEMATODE IN BRITAIN[1]

B. G. PETERS[2]

The nematodes are a very common and widespread group of animals. Most of them are free-living (*i.e.*, are not parasites), and these are to be found in soil, and in fresh and salt water, in large numbers. They may also turn up in the most unlikely places such as vinegar, or in book-binder's paste that has turned sour. Although these free-living nematodes are so common, few people ever see them because they are usually less than 1/20" long, and usually very thin and transparent. A microscope is needed to examine them.

Another group of nematodes is parasitic in animals and in man; most of these are quite large and can be seen with the naked eye: the "round-worms" of dogs and cats and pigs, and the pin-worms of children, are examples.

A third group of nematodes is responsible for damaging plants, either as true internal parasites (living within the plant tissues) or as external parasites, sucking the plant sap from the outside. More than 70 different species of internal plant-parasites are known at present and almost as many external parasites. Most of the latter live in the soil around the roots, which they attack, but a few are found above ground in the developing leaf-buds. Of the true internal plant parasites, some species live in the roots, others in the stems, or in the leaves or flowers.

Most of the plant parasites are too small, thin and transparent to be seen without a microscope so, if you see worm-like animals wriggling about in plant tissues, you can be fairly certain they are not nematodes: they are more likely to be insect larvae.

Usually, any one species of nematode will attack only a few different kinds of plants, and that gives us our best method of control: by rotation of crops.

Nematode diseases, in animals as well as in plants, are mainly a product of civilization. Under wild, natural conditions a rough balance is achieved — a kind of "live and let live" arrangement. The parasites are there, in small numbers, but they rarely cause disease. Thus the semi-wild sheep that roam the Welsh mountains have a few nematode parasites, but no nematode disease. The sheep have a free range over a vast area so that the ground never becomes badly contaminated with nematode eggs. But, herd these sheep together in large numbers on confined pastures, and in a few years young lambs are *dying* of nematode diseases. The reason is that herding together in a confined space leads to an enormous multiplication of the parasites, to a level never found in nature. The sheep can stand a certain number without harm; above that number symptoms of disease appear, and finally the parasite gets the upper hand.

It is rather similar with plants. Although they do not range around,

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they are found under wild conditions scattered about, singly or in clusters, *with other kinds of plants in between*. Even if one cluster gets attacked by nematodes, and even destroyed, the nematodes have a difficult task in finding other plants of the same species nearby. But if you bring together a lot of plants of the same species in one field, and keep growing them there year after year, conditions are ideal for the multiplication of nematodes (and other pests and diseases). Of course, if the particular species of nematode which attacks that plant is not present, you may "get away with it" for a long time. But the chances are that, sooner or later, the parasite will be accidently introduced and then, sooner or later, disease is almost certain to follow.

This happened to the potato crop in the British Isles. Potatoes have been grown there for hundreds of years. But when the human population jumped from 9 million in 1800 to 33 million in 1900, potatoes began to be grown intensively. Specialist potato farmers appeared, growing nothing but potatoes, year after year, on the same land. They had their troubles. Blight would sometimes ruin the crop. But, on the whole, they got away with it. Then, early in this century, a new parasite appeared (from God knows where): the "golden nematode." It was first found in Scotland in 1913 and in England in 1917, but by that time it must have been already widespread, and in sufficient numbers to cause disease. It now infests more than half our potato land in all the principal potato growing areas.

In the same year, 1913, it was found in Germany and shortly after in Denmark and Sweden. Since then it has been found in all countries round the Baltic Sea, and in recent years has invaded Holland, Belgium, France, and Austria. Outside Europe it has been found in Long Island, and (last year) in South America.

Long Island is not far away. The Federal Quarantine Service is making a valiant attempt to keep it from spreading to the mainland. But, sooner or later it may cross the Sound. It may have crossed already, for it might be present in a soil for several years before there is a reasonable chance of detecting it. You may, therefore, be interested to know something about it.

The Golden Nematode is a species of *Heterodera*, and all the Heteroderas are highly specialized as internal parasites of the underground parts of plants. The larvae and the adult males are thin, transparent, and worm-like, like most other nematodes, but the females are quite untypical. Instead of laying their eggs, they retain them inside the body, which swells up to a spherical shape with a neck sticking out, like a child's balloon. The young stages live wholly within the root, feeding on the plant tissues, but the swollen part of the female bursts through to the outside in some 4 or 5 weeks after infection. At this stage the females are transparent but, in a few weeks, they turn a golden yellow and then brown. This is an outward sign of an inward chemical change, for the outer skin becomes tanned to a leather-like substance. At this stage the female worm dies and drops away from the root into the soil: a dead, leather bag packed with living eggs. These brown, dead females are the so-called "cysts." They measure about 1/50 inch across and are just visible to the naked eye under favorable conditions: the golden yellow stage attached to the roots is the most clearly visible.

What makes these Heteroderas so difficult to control is the fact that the eggs can survive for many years (ten or more) within the protecting cyst. Normally, about one-half of them hatch each year so that a cyst starting with 100 eggs might contain (in successive years) 50, 25, 12, 6, 3, *etc.* Depending on the size of the cyst, it may start with 50 to 600 eggs inside it. In the Golden Nematode there is only one generation each year.

If the root of a potato, tomato, or some closely related plant happens to grow near a cyst, nearly all the contained eggs will hatch within a few days, the hatched larvae crawling out of the cyst and boring into the root. These host plants produce a substance which diffuses from the roots and greatly stimulates hatching. Chemists at Cornell and at Cambridge (England) are trying to discover what this stimulating substance is.

A potato root consists of a thick outer skin or "cortex," and a small central core or "stele" in which lie the vessels which conduct water and plant foods along the root. The Golden Nematode larva bores into the root by means of a sharp spear, rapidly striking through the mouth and acting like a concrete-breaker. The larva comes to lie in the cortex with its head in or near the stele, where it feeds by puncturing the plant cells and sucking out their contents. The plant reacts by forming giant cells in the stele — possibly in an effort to shut off the parasite — and these giant cells tend to block the conducting vessels in the stele. This means that water and plant foods cannot flow so readily. If enough larvae attack a single rootlet, the stele may become completely blocked and the rootlet will die. In this case the plant responds by forming new roots. There is some evidence that a light attack acts like a tonic, stimulating the plant to better growth in the way that pruning or disbudding does. So it is largely a question of numbers whether or not the parasite causes disease symptoms.

From what has been said about root damage, these symptoms can be foreseen. They are symptoms of food and water shortage. The plants are small, stunted, and wilt quickly in dry weather. The lower leaves soon turn brown and die. The tubers produced are few and very small, but not otherwise abnormal. In badly infested fields the yield of tubers goes down and down. Finally there is a complete crop failure. In England there have been many cases of the crop weighing less than the seed planted: that is a crop failure.

Perhaps, at this point, I may give you a few figures to show what this parasite means to us, and might come to mean to you if you were not alert. In the first place comes the difference in scale between our two countries: you have 3 times our population and 32 times our land area, so that you have 78 persons to every 1000 acres, and we have 833 persons. Nineteen per cent of your total area is arable land, whereas 31 per cent of ours is arable (we have fewer mountains, lakes and prairies). Potatoes are clearly more important to us than to you, since one-half of 1 per cent of your arable land is given to potatoes, but more than 7 per cent of our arable soil. You grow about 12 acres of potatoes for every 1000 persons, whereas we grow 26. Therefore your total acreage of potatoes is only slightly higher than ours, and (since our yield per acre is slightly better than yours) we actually produce slightly more than you: over 9 million long tons annually.

The Ministry of Agriculture has conservatively estimated the annual loss caused by the Golden Nematode at £2 million Sterling. This means between $1.00 and $2.00 on every ton of potatoes, or about $10.00 annually on each potato acre. For farmers in a tough spot, this can mean the difference between sink or swim.

It is important to realize how this parasite gets spread about. The cysts are dead and cannot move of themselves. The newly hatched larvae crawl through the soil, but we are sure they do not move more than an inch or two in one season. Short-distance spread is due to normal cultivation-processes. If an infestation starts with one, or a few, cysts at one point in a field, no symptoms need be expected for several years. The first sign will be a small patch, a few feet across, in which the plants are stunted and wilt easily. If potatoes are grown annually, this patch gets a foot or more larger each year. In the meantime, other small patches are likely to appear and grow, until finally the whole field becomes infested.

Long distance spread, from field to field or farm to farm, is commonly by means of soil adhering to roots, tools, and farm implements. In a moderately heavy infection one might expect about 30 cysts in every ounce of soil: on a wet day a few ounces of soil are likely to be carried on tractor wheels, to say the least. Cysts are also carried in the soil around cabbage and other seedlings, in potato bags, and on the tubers themselves. On light soils, cysts may also be blown as dust.

With potatoes grown every year, an infestation is likely to multiply approximately 20-fold each year. Part of the increase goes to extend the size of the patch, so that the density of cysts at any one point shows a lower increase, say about 10-fold each year. This continues until there are about 7 cysts to every 5 pounds of soil. At this level, given perfect soil-sampling, there is an even chance that the infestation will be found in a ½ pound sample of soil (and, of course, an even chance that it will *not* be found). This corresponds to a rate of 3.5 million cysts per acre: not until this level is reached is there a reasonable chance of detecting it. One more year means about 14 cysts, and a second year about 140 cysts per pound. At this level larvae symptoms should appear. Thus an even chance of detection comes only two years before symptoms of disease.

At the symptom-level the rate of increase starts to fall below 10-fold: the smaller plants are not capable of supporting so many cysts. The normal upper limit is about 40,000 cysts per potato plant. Finally, at the crop-failure level of cysts (200 or more to each pound of soil), the multiplication factor sinks to 1 or even less. That is to say, the nematode population may even fall, owing to a poor crop.

The infested plant must be thought of as dividing its efforts between producing tubers and producing nematode cysts. Anything that is done to improve the yield of tubers will also improve the yield of cysts. Of every pound of fertilizer used, part will be wasted, part will go to form tubers, and part will be used to grow more cysts.

At the failure level, the farmer is forced to grow some crop other than potatoes or tomatoes. Under these conditions, as I have said, the population will probably be halved each year. After some years it may be possible to introduce a regular rotation, designed to keep the nematode population below the symptom-level. The length of this rotation depends on local conditions of soil and climate. If we assume a 10-fold

increase in population in the potato year, and a 50 per cent decrease every other year, then we shall not quite succeed with a 4-course rotation, with potatoes one year in 4. For, starting at 100 larvae per unit, the population will be 50, 25, and 12.5 in the three off-years, after which the potato crop will send it up to 125. This would lead to a gradual average increase. The actual fact is that a 4-course rotation may be quite satisfactory on some soils, whereas 6 courses are needed on others. In general, light sands and silts, and black peat soils favor the growth of the parasite and so demand longer rotations than does a heavier clay soil.

This crop rotation is, at present, the only satisfactory method of control. It is unpopular with our potato farmers, and naturally so, for their whole farm economy is geared to growing potatoes, and these are a more valuable crop than most alternatives — *normally*. But after one or two crop failures they are compelled to change their farm economy and to rotate crops.

Other possible methods of control are sought through plant breeding and chemical treatment. In recent years wild potato species have been brought to England from South America, and plant breeders have found one or two of these to be highly resistant to the attacks of the Golden Nematode. The problem now is to breed this resistance factor (along with other desirable factors) into varieties producing a high yield of good quality. This is quite a problem and will at least take several years.

Soil fumigation has given promising results in some places and poor results elsewhere. It can never be a means of total eradication on a field scale, but it may prove to be economic in the sense that the increased crop of tubers may more than pay for the treatment. Even this is not enough to make the treatment economic, for if treatment doubled the yield from 2 to 4 tons per acre, it still would not pay to grow the potatoes even if the increased yield met the treatment costs.

The Golden Nematode also attacks tomatoes and, in England, this crop is grown under glass and is much more valuable, per acre, than potatoes. Soil fumigation is much cheaper than steam-sterilization (though usually less effective) and is becoming a widespread practice in our glass-houses.

No fumigant is worth considering unless it kills at least 96 per cent of the eggs encysted in the soil, for the natural mortality without any fumigant is at approximately this level. Assuming a plant to be able to carry 40,000 cysts, and the cysts to carry an average of 50 eggs each, the product is 2 million eggs. If half of these are males, there is still a potential of one million females. But next year's plant may carry only 40,000 of these, or 4 per cent, so the net natural mortality must be about 96 per cent. In other words, if a fumigant leaves a residue of 4 per cent of eggs still living, that should be sufficient to saturate the next potato crop.

Apart from soil fumigants, other chemical treatments are under experimentation, including antibiotics and substances of the plant-hormone type. It is always possible that something really good will be found. But until that day, we in England are preaching sound husbandry. And growing the same crop in the same land year after year, indefinitely, is not our idea of sound husbandry.

POTASH and POTATOES

Growing potato plants will show their need for potash by leaves that have an unnatural, dark green color and become crinkled and somewhat thickened. Later on, the tip will become yellowed and scorched. This tipburn then will extend along the leaf margins and inward toward the midrib, usually curling the leaf downward and resulting in premature dying. It pays to watch for these signs, but it is a far better practice to fertilize with enough potash so as never to give them a chance to appear.

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